TATION PAPER NO. 21 JANUARY 1953

INTERCEPTION OF RAINFALL IN A YOUNG LOBLOLLY PINE PLANTATION

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Acknowledgement

This study was a project of the entire staff of the Piedmont Research Center. Credit is due D. F. Olson, Jr. and L. J. Metz for their assistance in planning the study and for statistical analyses. E. L. Brown designed and installed the stemflow gutters. W. Cagle and W. P. Bailey made most of the measurements and necessary compilations of data.

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INTRODUCTION

Those who have sought refuge during a storm have found a tree to be an effective umbrella for a light shower but leaky in a heavy rain. Even so, it is usually possible to stay slightly more dry under forest canopy than in the open. That is because a portion of the rain is stored on leaves and branches and eventually evaporated back to the air. The term interception is used for both the process and the amount of water thus dissipated. If one watches the rain drops, he can see how the process works. The first raindrops that strike the foliage spatter out, wetting the leaf surface. Finally the leaves are thoroughly wetted and water begins to drip off to the ground. Of course, some raindrops find openings in the tree crown and fall through directly to the ground. A part of the rain falling onto leaves and twigs flows from them to larger branches and finally runs down the trunk to the ground. The portion which is led to the ground down the stem is called stemflow, while that falling directly to the ground or dripping from twigs and leaves is called throughfall because it passes through the canopy. The sum of throughfall and stemflow or the total rain reaching the ground beneath a plant canopy is net rainfall.

Because there is a difference in density and arrangement of foliage for different tree species, much speculation and some measurements have been used to compare the net rainfall beneath stands of various tree species.1/ In connection, with a study of soil moisture on the Calhoun Experimental Forest2/ it was necessary to measure the net rainfall under a young loblolly pine plantation. The results of that study are reported here.

1/ For a discussion of interception and literature references, the reader is referred to: Kittredge, J., Forest Influences, McGraw-Hill Book Co., New York, 1948.

2/ Located 7 miles southwest of Union, S. C.

DESCRIPTION OF THE STAND

The trees were planted as one-year seedlings in February 1941. The intended spacing between trees was 6 feet each way but the actual spacing was about 6.5 feet. In the period May 1950 to March 1951 during which observations were made, the trees were in their tenth growing season after planting. There were an average of 760 trees per acre with an average d.b.h. of 5.3 inches and height of 31 feet. A few trees were as large as 7 inches in diameter and 35 feet in height. The basal area per acre was 103.3 square feet. On 10 sample trees, the average length of stem bearing live branches was 13.6 feet, which was 44 percent of total height. Although the canopy was rather dense in appearance, the total projected crown area based on the sample trees was 25,300 square feet per acre, indicating that only 58 percent of the ground surface in the plantation was directly below tree crowns.

HOW MEASUREMENTS WERE MADE

Throughfall

Two rain gages were used beneath the canopy to measure throughfall and two in nearby openings to determine rain in the open. Figure 1 shows their general location. The four lines along which rain gages under the canopy were moved were laid off at right angles to the planting rows. On each line, 10 stakes were set at 4-foot intervals (fig. 2). Rain gages were moved from one stake position to another after each storm and the cycle was repeated on a line until four storms were sampled at each position. The rain gages were on lines 1 and 2 from May 3 to August 23, 1950 and on lines 3 and 4 from August 24, 1950 to March 30, 1951.

Statistically, it would have been better to randomize the rain gage positions. The systematic arrangement used insured sampling a wide range of conditions and gave a good estimate of average interception in the plantation but may invalidate statistical analyses based on random distribution. In spite of this objection, the comparisons between lines and positions were made by ordinary covariance methods. There was no advantage in the resampling of positions on a line and it would have been better to occupy completely randomized locations; truly random location is recommended for future studies.

The rain gages used are similar to the conventional non-recording Weather Bureau rain gage except that they are only 10 inches high and the inner cylinder overflows into the large container after 0.5 inch of rain.[3/] These gages can be set directly upon the ground without external support, which made it easy to move them to new locations.

3/ The rain gages were designed by the Division of Fire Research, Southeastern Forest Experiment Station.

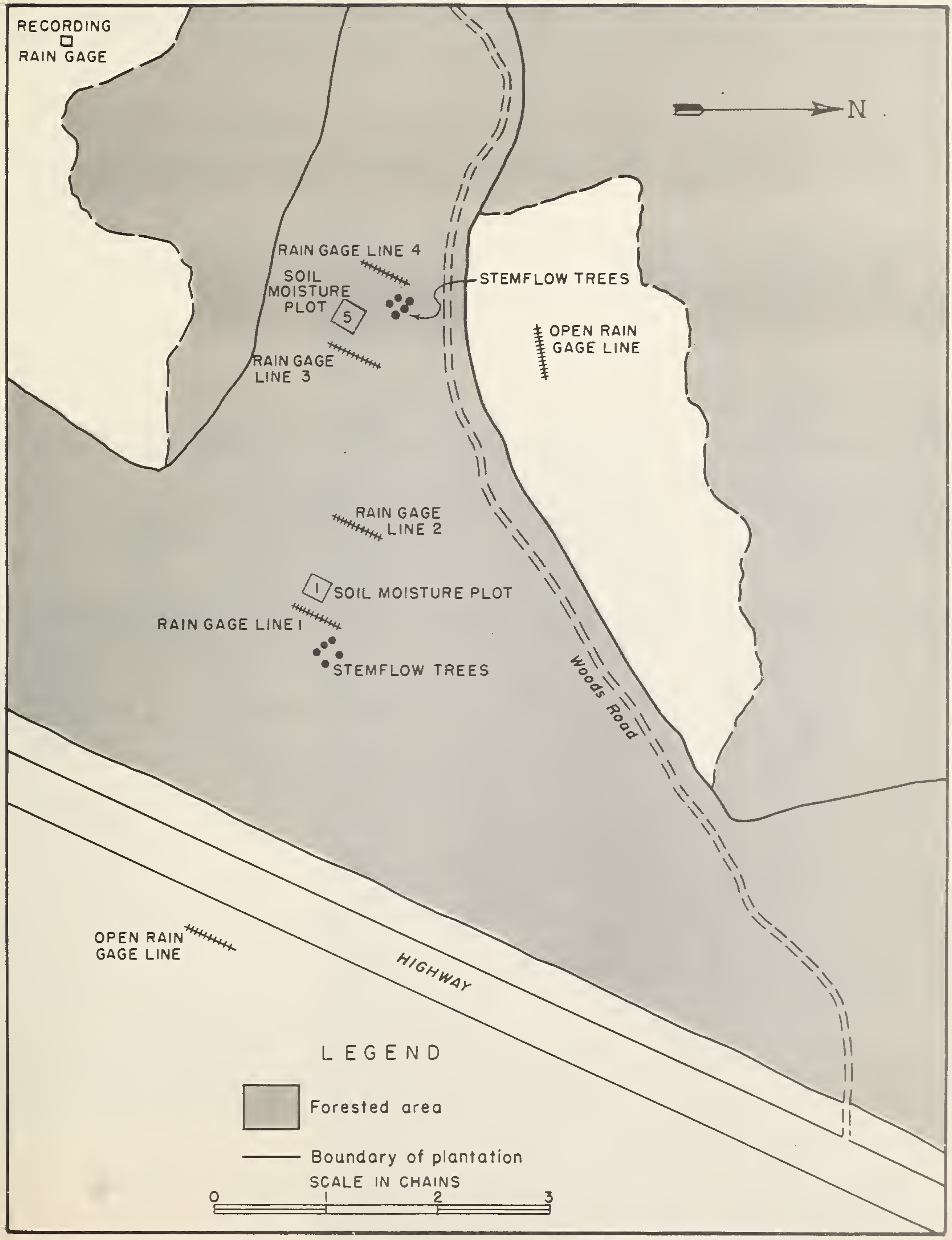

Figure 1.--Location of rain gages and stemflow trees in the loblolly pine plantation.

Rainfall in Open

As shown by figure 1, the open rain gages were in clearings only a short distance from the plantation. In addition, a recording rain gage of the regular precipitation network of the experimental forest was also nearby. The record for all gages in the open was remarkably similar, indicating that rainfall was uniform over the observation area.

Figure 2.--Measurement of throughfall. Numbered stakes mark sampling positions. The undercanopy rain gages are set directly upon the ground. Note the upthrust branches of the young loblolly, believed to cause the high proportion of stemflow.

Stemflow

Stemflow was measured on 10 trees. They were chosen by locating a point at random near the locations on which throughfall was measured. The nearest five trees to the point were equipped for stemflow measurements. Stemflow was diverted from the tree trunk by a spiral tin gutter nailed to the tree and sealed by asphatum cement. Bark was smoothed for about 2 feet above the gutter. The gutters were made narrow to minimize the amount of rain falling directly into them. Water was lead by a rubber hose to 5-gallon cans. From two to five cans were connected together to provide the capacity needed for a given tree. After each storm, the cans were weighed to the nearest 2 ounce on a small platform balance (fig. 3). This was convenient and furnished a high order of accuracy. There was some difficulty in keeping hoses free from bark, pitch and trash, and continual vigilance was necessary to keep them open. Stemflow was measured between August 12 and December 10, 1950, and good records were obtained for 17 storms during that time.

Figure 3.--Weighing the collection cans to determine amount of stemflow.

A comparison of stemflow in relation to rainfall was made for the two groups of five trees and there was no significant difference between them. It was then assumed that any other group of five trees in the stand would give similar results, and measurements for the 10 trees were combined to give total stemflow in pounds per storm. The total stemflow for these trees in pounds was multiplied by 76 (there were 760 trees per acre) and was converted to inches depth to express it in the same unit as rainfall is measured.

RESULTS

Both throughfall and stemflow were found to be linear functions of the amount of rain per storm (fig. 4). Throughfall did not occur when rainfall was 0.02 inch or less. The equation for throughfall is:

Throughfall = .732(Rain in open) -.016 .... 1.

Stemflow was insignificant for storms less than 0.10 inch. For these small storms, net rainfall can be obtained from the throughfall equation. The equation for stemflow is:

Stemflow = .222(Rain in open) -.018 .... 2.

The total rainfall reaching the ground under the trees for storms 0.10 inch and larger can be obtained by solving both equations 1 and 2 and adding the results. However, it is more convenient to estimate net rainfall by the equation for net rainfall given below. This equation applies only to storms of 0.10 inch or larger.

Net rainfall = .954(Rain in open) -.034 .... 3.

The error of estimate for the throughfall equation is 0.11 inch for an individual position within the stand with a mean storm size of 0.45 inch. The correlation coefficient is 0.92. The standard error for stemflow is .008 inch for a mean storm size of 0.80 inch. The correlation coefficient for stemflow is 0.99.

The relationship of throughfall to rain in the open was similar on each of the four under-canopy rain gage lines, and regressions for each line were not significantly different. This indicates that throughfall is essentially similar throughout the plantation. A test was made for differences associated with season or time by computing regressions for individual cycles on the lines. Difference in cycles was not significant and it may be inferred that throughfall is not influenced by season. Measurements were classified into the following storm-size classes; .01-.10, .11-30, .31-.57, .57-1.00, and above 1.00 inch. Regressions for these individual groups did not differ significantly.

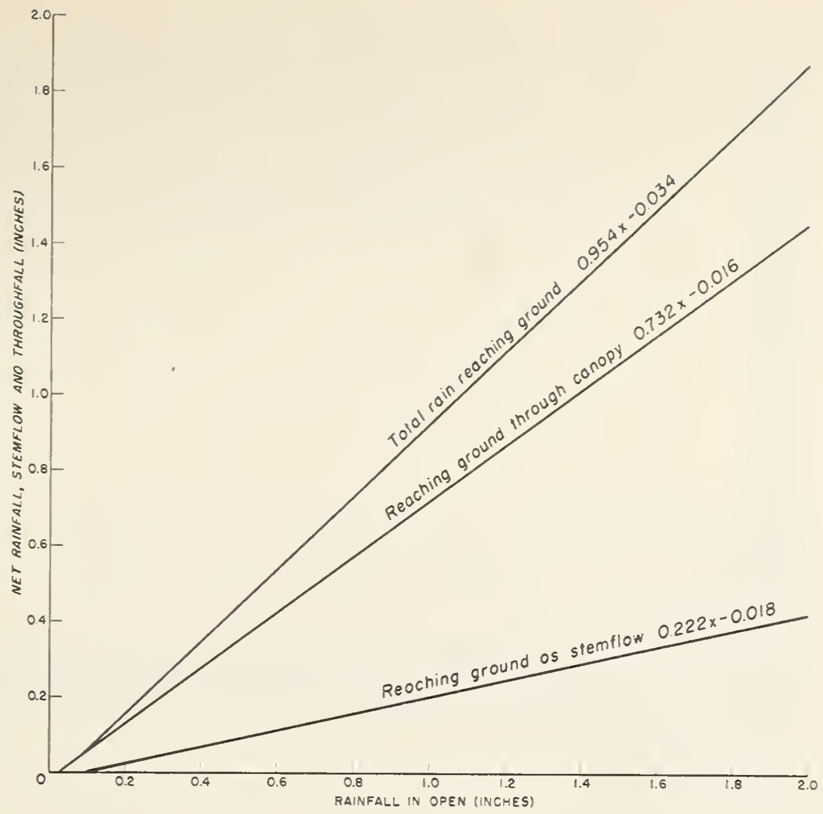

Figure 4.--Total net rainfall, throughfall and stemflow as compared with rain in open. Loblolly pine 10 years after planting.

These comparisons indicate that throughfall can be estimated with confidence from rain in the open without additional refinement.

An effort was made to relate stemflow to tree characteristics. There was a tendency for stemflow to be larger for trees taller than their neighbors or with more live branches in the crown. However, there was so little difference in the appearance of individual trees that classification appeared to serve no practical purpose.

Interception has been frequently expressed as a percentage of total rainfall. To facilitate comparison with such information, figures 5 and 6 were prepared to show the percentage of canopy interception, stemflow, and their sum in relation to storm size.

Actually the amount intercepted from light showers is of little significance because even if it did reach the ground it would have neglible effect on soil moisture. In fact, during the growing season, a few hundredths of an inch on the foliage is more helpful to the trees than the same amount applied to the soil. Wetting the leaves serves to reduce transpiration rates, and during periods of soil moisture stress this may be of considerable benefit.

For periods of time such as months, seasons, or years the amount and percentage of rainfall that reaches the ground can be expected to show considerable variation. Less rainfall will reach the ground in a period when storms are small as compared with similar time intervals with the same total rainfall but received in larger storms. For example, in a single storm of 1.00 inch in the open, 0.92 will reach the ground

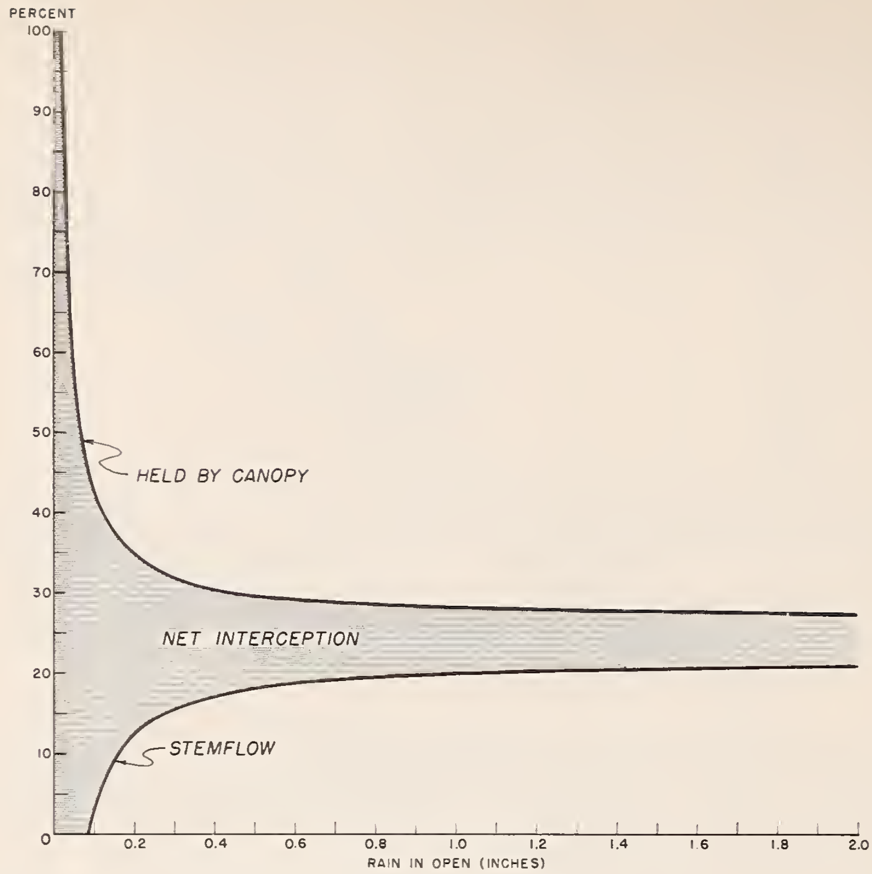

Figure 5.--Throughfall and stemflow as a percentage of rain in the open.

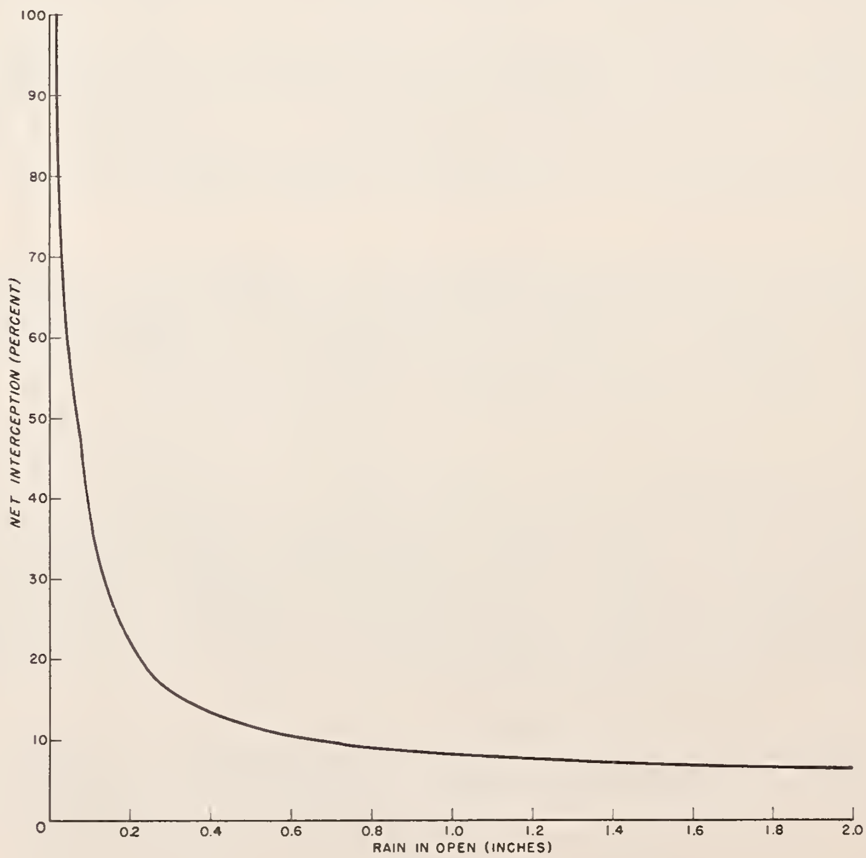

Figure 6.--Net interception as a percentage of rainfall in the open.

below the trees, but when five storms of 0.20 inch occur the total net rain under the tree crown is only 0.78 inch. Table 1 gives the estimated net rainfall under the loblolly plantation for two years differing considerably in total rainfall. Although shown as monthly totals, net rainfall was actually estimated for each storm.

Table 1.--Estimated net rainfall under 10-year-old loblolly pine, with rainfall as received in 1948-49 and 1949-50 at Union, S.C.

Period	1948-49			1949-50		
	Rainfall		Reaching ground under trees	Rainfall		Reaching ground under trees
	In open	Under trees		In open	Under trees	
	Inches	Inches	Percent	Inches	Inches	Percent
October	1.54	1.21	79	2.32	1.93	83
November	10.09	9.11	90	1.61	1.39	86
December	4.42	3.88	88	2.30	1.85	80
Fall total	16.05	14.20	88	6.23	5.17	83
January	4.43	3.96	90	2.51	2.08	83
February	5.58	4.98	89	1.50	1.19	79
March	1.89	1.53	81	3.96	3.35	85
Winter total	11.90	10.47	88	7.97	6.62	83
April	5.58	4.76	85	1.49	1.28	86
May	3.01	2.57	86	4.15	3.66	88
June	2.15	1.84	86	2.82	2.28	81
Spring total	10.74	9.17	85	8.46	7.22	85
July	3.47	2.89	83	3.49	2.86	82
August	12.67	11.68	92	3.10	2.69	87
September	2.43	2.01	83	3.07	2.71	88
Summer total	18.57	16.58	89	9.66	8.26	85
Annual total	57.26	50.42	88	32.32	27.27	84

While net rainfall per month is only 80 to 90 percent of rain in the open, it is believed the redistribution of rainfall as a result of stemflow is of more importance. Each of the young pines is a rainfall concentrator receiving rain over its crown spread and funneling a large part of it down the trunk to the ground. A large volume of water is thus accumulated and applied to a narrow band around the trunk. In this plantation, for example, during a 1-inch rain the average tree leads an average of 8 gallons to the ground down the stem. To illustrate the amount of stemflow, table 2 gives the estimated stemflow as inches per acre and as gallons per tree by months for the years 1948-49 and 1949-50.

Table 2.--Estimated stemflow per acre and per tree, with rainfall as received in 1948-49 and 1949-50 for 10-year-old loblolly pine plantation

Period	1948-49			1949-50		
	Rain in open	Stemflow		Rain in open	Stemflow	
		Per acre	Per tree		Per acre	Per tree
	Inches	Inches	Gallons	Inches	Inches	Gallons
October	1.54	.23	8	2.32	.36	13
November	10.09	1.94	69	1.61	.27	10
December	4.42	.81	29	2.30	.31	11
Fall total	16.05	2.98	106	6.23	.94	34
January	4.43	.82	29	2.51	.38	14
February	5.58	1.04	37	1.50	.19	7
March	1.89	.26	9	3.96	.60	21
Winter total	11.90	2.12	75	7.97	1.17	42
April	5.58	.97	35	1.49	.26	9
May	3.01	.46	16	4.15	.75	27
June	2.15	.38	14	2.82	.41	15
Spring total	10.74	1.81	65	8.46	1.42	51
July	3.47	.36	13	3.49	.49	18
August	12.67	2.56	91	3.10	.74	26
September	2.43	.36	13	3.07	.53	19
Summer total	18.57	3.28	117	9.66	1.76	63
Annual total	57.26	10.19	363	32.32	5.29	190

The volume of stemflow is of benefit to the tree because it is added to the soil where it is readily available to roots. Moreover, it is frequently of sufficient quantity to cause accretion of moisture to considerable depth in the soil. The area at the tree base often receives a thorough soaking when the space between the trees is only dampened. As a result, moisture recharge may take place to considerable depth near the trees when only the surface horizon in the interspaces receives moisture. Neglect of this unequal application of water would cause an underestimate of the water available to the trees and of the moisture added to subsoil horizons.

Stemflow water is added to the ground where conditions are favorable for it to be rapidly absorbed. Around the base of pines there is normally an accumulation of needles, bark and other debris (fig. 7) which provides a favorable condition for water entry. Deep penetration of water is also facilitated by the passageways made by roots and associated organisms. As planted trees develop on old fields, conditions causing rapid infiltration of water are created first near the base of trees. Thus the concentration of a sizeable portion of rainfall in that zone by stemflow aids in bringing about a reduction in surface runoff at an earlier stage of plantation development than would be the case if rain reached the ground more evenly distributed. If forest fires remove the debris around the tree bases, an unfavorable condition is created for water entry. Examination of the area around the stems after a fire frequently shows a ring of bare, crusted soil washed clean of charcoal by stemflow water (fig. 8).

Figure 7.--The accumulation of needles, bark, and debris at the base of trees creates favorable conditions for the rapid infiltration of water flowing down tree trunks.

Figure 8.--Fire removes the protective litter from the ground at the base of trees. Stemflow water then frequently becomes surface runoff as shown above, where the soil in a ring around the trees has been washed free of charcoal and is packed and bare.

The quantity of stemflow reported here for young loblolly is at the upper range of stemflow values reported in the literature for various species. The crown form is the best explanation for the large volume of stemflow. Young loblolly pines have sharply uptnrust branches terminated by a cluster of long needles. This arrangement forms an efficient system for leading water to the trunk. The same branch arrangement and even longer needles characterize young slash and longleaf pines. Therefore, it is expected that stemflow for those species is very likely comparable to loblolly pine. No information is available to estimate stemflow for older loblolly pine.

CONCLUSIONS

The reduction in net rainfall due to interception in a plantation of 10-year-old loblolly pine is less than was expected. On an annual basis, net rainfall will average about 86 percent of rain in the open. Only a small part of heavy rains is intercepted. Reduction in surface runoff caused by the development of loblolly pine on old fields is not due to interception but to improved conditions for intake of water into the soil. A sizeable proportion of rainfall does reach the soil as stemflow and this aids in reducing runoff by concentrating water where conditions are ideal for water entry. Stemflow also makes more water available to the trees than would be the case if rainfall reached the soil with uniform distribution.

It is not known whether this high proportion of stemflow is maintained as loblolly increases in height and age. In any studies of net rainfall under stands of the Southern pines, stemflow is a factor which must be considered.

SUMMARY

In a 10-year-old planting of loblolly pine near Union, S. C., the amount of rainfall reaching the ground by passing through the tree crowns and as flow down the tree trunks was measured. Regression equations for estimating the net rainfall, throughfall, and stemflow on the basis of rainfall in the open were determined. Net rainfall under the trees was found to average about 86 percent of rain in the open. A considerable proportion of rainfall reaches the ground as flow down the stems. The redistribution of rainfall due to this concentration of rain water at the base of trees is believed to be significant to tree growth and soil moisture. No seasonal differences in the proportion of net rainfall were found. Results apply only to precipitation occurring as rain.

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